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Energy and Environmental Analysis, Inc.
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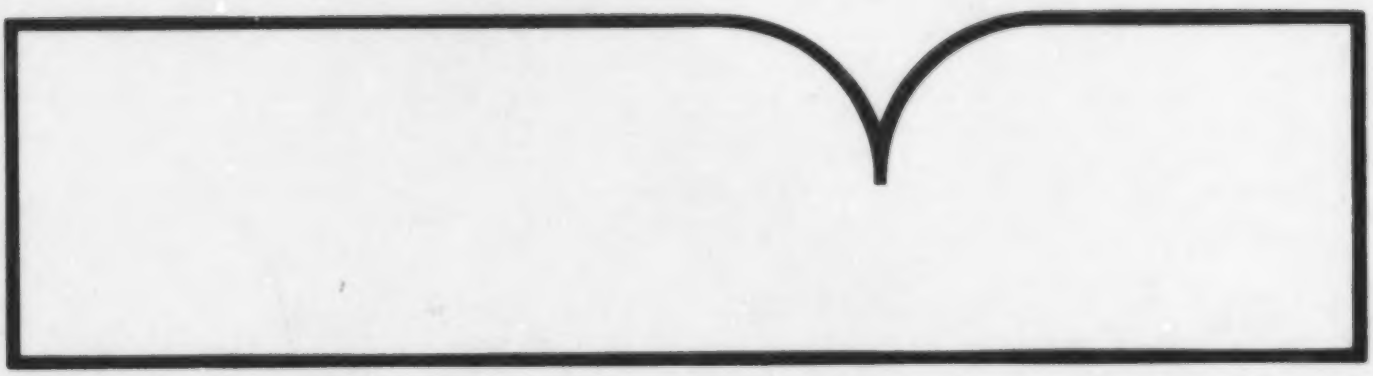

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Development of the Industrial Combustion Emissions Model for Acid Rain Analyses

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16. ABSTRACT The paper discusses forecasts of industrial combustion emissions being developed by the U.S. EPA as part of the National Acid Precipitation Assessment Program (NAPAP). The Industrial Combustion Emissions (ICE) Model will estimate sulfur dioxide (SO2), nitrogen oxides (NOx), and primary sulfate emissions from industrial fossil-fuel-fired boilers. These forecasts will be generated on a state-level basis. Alternative pollution control scenarios will be evaluated for reducing emissions from both existing and new industrial boilers. The ICE Model also evaluates the selection of fossil fuels for industrial steam generation. Capital and operating/maintenance costs for boilers and pollution control equipment, plus the costs of alternative fuel types, are used in selecting the fuel type for individual industrial boilers. Since emission rates vary significantly between coals, residual fuel oils, and natural gas, the fuel choice decision is a critical factor in estimating aggregate levels of SO2, NOx, and primary sulfates.

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Analyzing	Fossil Fuels	Acid Rain	14B	21D
Precipitation	Boilers	Industrial Boilers	04B	13A
Acidification	Sulfur Dioxide		07B, 07C	
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ABSTRACT

DEVELOPMENT OF THE INDUSTRIAL COMBUSTION EMISSIONS MODEL FOR ACID RAIN ANALYSES, K.F. Held, Energy and Environmental Analysis, Inc., 1655 N. Ft. Myer Drive, Arlington, VA 22209, and J.D. Mobley, Air and Energy Engineering Research Laboratory, U.S. Environmental Protection Agency, Research Triangle Park, NC 27711.

Forecasts of industrial combustion emissions are being developed by U.S. EPA as part of the National Acid Precipitation Assessment Program (NAPAP). The Industrial Combustion Emissions (ICE) Model, an extension to the modeling framework found in the Industrial Fuel Choice Analysis Model (IFCAM), will estimate sulfur dioxide (SO_2), nitrogen oxides (NO_x), and primary sulfate emissions from industrial fossil-fuel-fired boilers. These forecasts will be generated on a state-level basis. Alternative pollution control scenarios will be evaluated for reducing emissions from both existing and new industrial boilers. The ICE Model also evaluates the selection of fossil fuels for industrial steam generation. Capital and operating/maintenance costs for boilers and pollution control equipment, plus the costs of alternative fuel types, are used in selecting the fuel type for individual industrial boilers. Since emission rates vary significantly between coals, residual fuel oils, and natural gas, the fuel choice decision is a critical factor in estimating aggregate levels of SO_2, NO_x, and primary sulfates.

Introduction

The Industrial Combustion Emissions (ICE) Model is a highly disaggregated and detailed process engineering model covering the consumption of fossil fuels (coal, distillate fuel oil, residual fuel oil, and natural gas) in industrial boilers. It was developed to help decisionmakers assess a wide range of energy, environmental, and cost impacts resulting from policy alternatives. The ICE Model is currently being used by the National Acid Precipitation Assessment Program (NAPAP) to project the impacts of alternative acid deposition control strategies.

The ICE Model is an extension of the model framework found in the Industrial Fuel Choice Analysis Model (IFCAM). IFCAM has been used for the past 7 years in EPA's review of the Industrial Boiler NSPS[1/] and has undergone numerous peer reviews. Much of the discussion below applies equally to both IFCAM and ICE. There are, however, some significant differences based on innovations incorporated in the ICE Model. The major innovations contained in the ICE Model are:

- A revised fuel choice decision logic that incorporates other factors as well as economic factors that influence fuel choice in boilers
- An extended time horizon to the year 2030
- State-level outputs
- Retrofit control options for existing boilers
- Forecasts of primary sulfate emissions

Approach

The ICE Model is a process engineering/simple accounting industrial boiler fuel choice model. This modeling technique simulates the effects of specific policies on technical alternatives through the application of engineering information at a disaggregated level.

Key input assumptions include:

- Base year boiler population characteristics
- Projected fuel prices and total industrial boiler fossil fuel demand
- Boiler and pollution control equipment cost estimates
- Local and Federal air emissions regulations

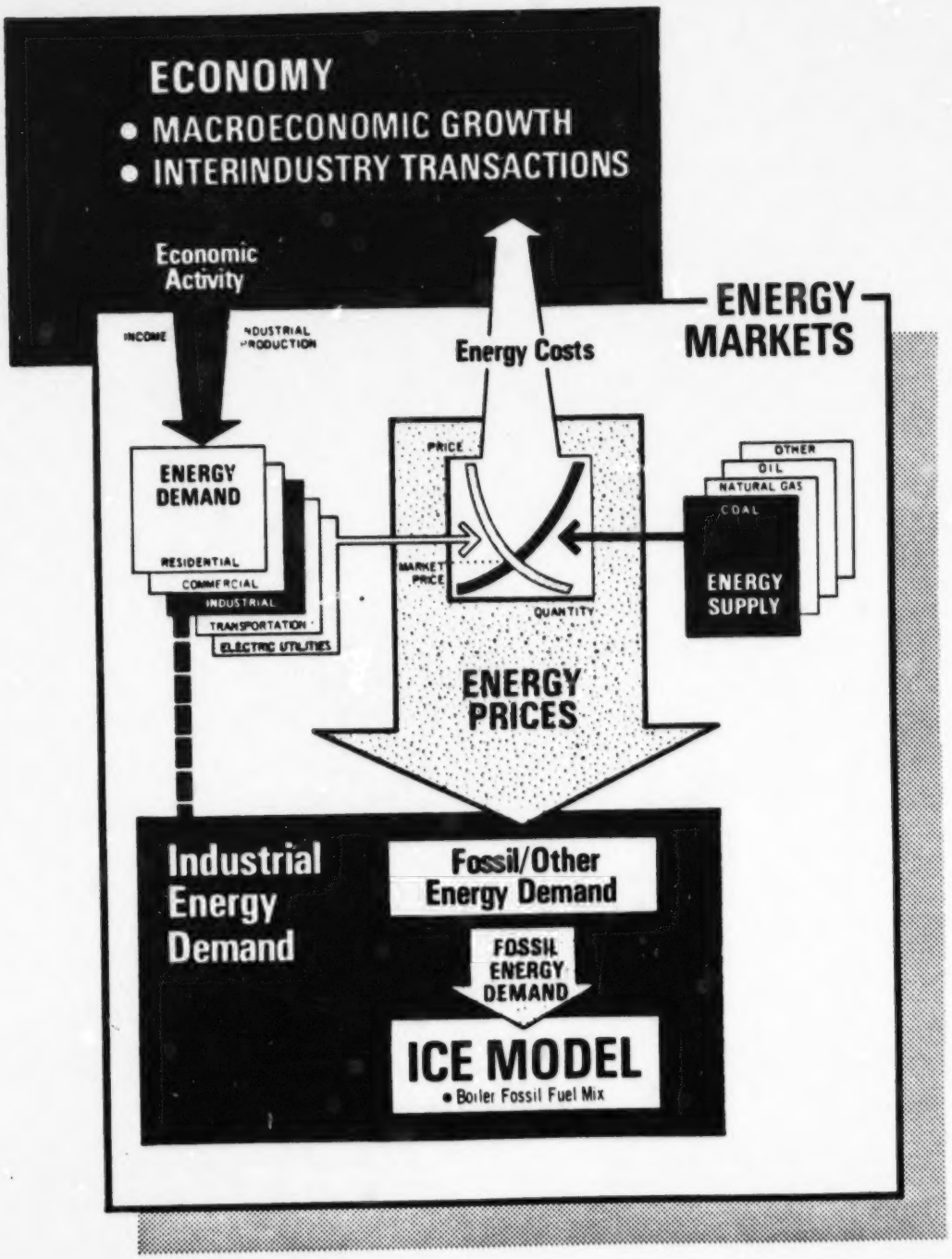

Figure 1 Context of current ICE model structure.

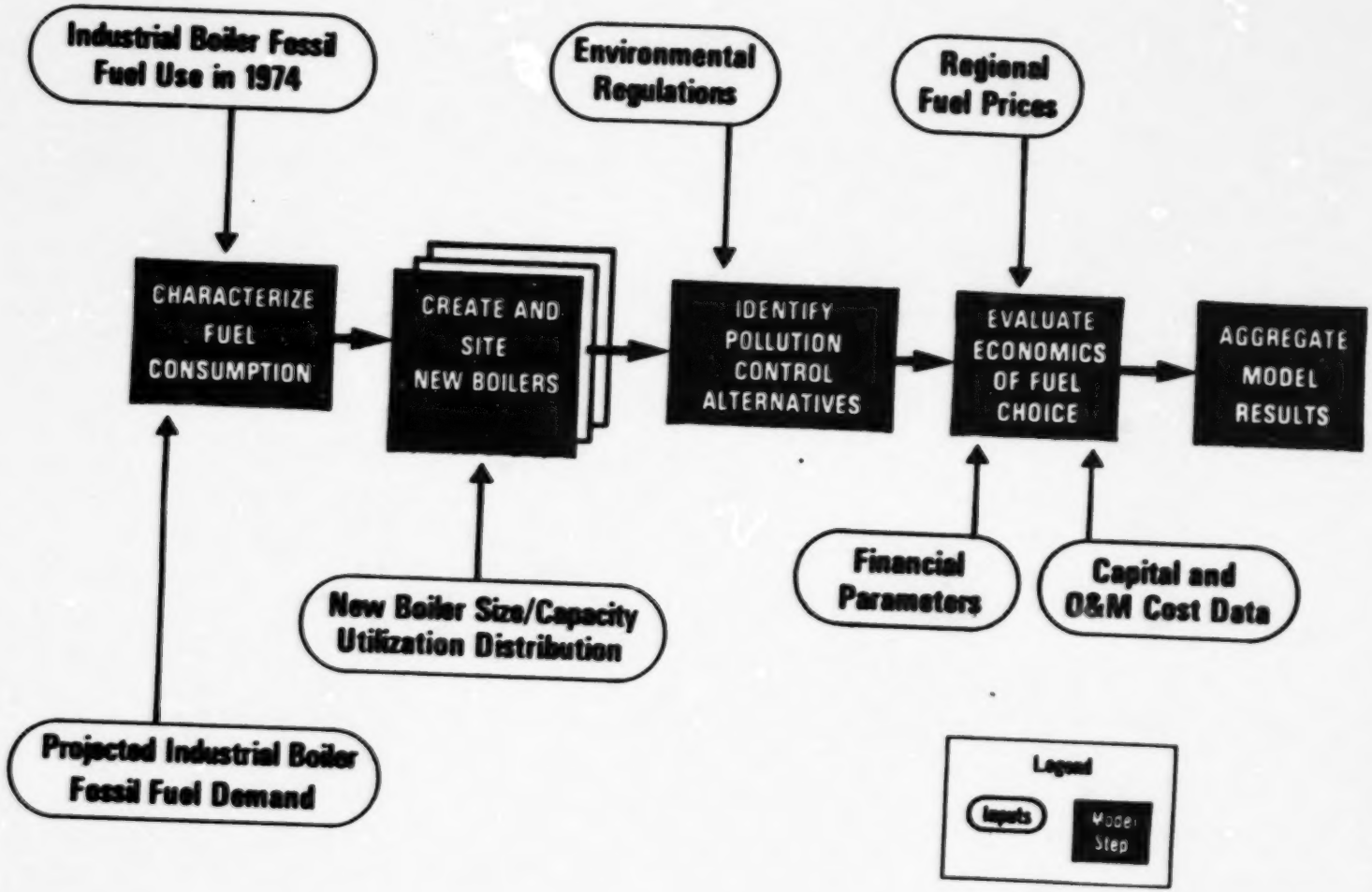

Figure 2 ICE model structure.

The basic approach in this model is to project the characteristics of the industrial boiler population and to make fuel choice decisions for different types of boilers (see Figures 1 and 2). The characteristics used to classify different boiler types include:

- New or existing unit
- Boiler size (10^6 Btu/hr heat input)
- Average annual capacity utilization rate
- Local and Federal sulfur dioxide (SO_2), particulate matter (PM), and nitrogen oxide (NO_x) emissions standards

Industrial boiler energy use is thus disaggregated by new and existing boilers of different sizes and annual capacity utilization rates. New and existing boilers are classified on the basis of the type of fuel they were designed to fire and whether they can be retrofitted to fire alternative fuels. Current modeling capabilities for pollution control systems include only conventional technologies. Eight size classes are delineated for boilers. There are five capacity utilization rate categories for boilers.

The ICE Model structure has been designed to evaluate alternative fuel price projections, government energy and environmental policy proposals, costs associated with firing alternative fuels, and other key model parameters. The fuel choice decision criterion includes a comparison of after-tax, discounted cash flows. Therefore, a variety of tax credits and changes in the tax treatment of capital (proposed to provide incentives to invest in coal-related equipment) can be analyzed using the model.

Major model outputs include:

- Projected emissions of SO_2, sulfates, and NO_x
- Projected industrial boiler fossil fuel demand by fuel type (coal, distillate fuel oil, residual fuel oil, and natural gas)
- Projected total capital and annual operating, maintenance, and fuel expenses

Model outputs are available by state and year (1985, 1990, 1995, 2000, 2010, 2020, and 2030).

Regulatory Options

Environmental regulatory policies can affect fuel choice by altering the relative costs of burning alternative fuels. Regulations relating to PM, SO_2, and NO_x emissions from fuel-burning sources include State and local regulations and Federal NSPS.

The ICE Model is capable of modeling alternative industrial boiler emission control options. The ICE Model can simulate the use of various types of flue gas desulfurization (FGD) systems (some with combined

SO_2/PM emissions control), various types of post-combustion PM emissions control, and two types of combustion modifications to control NO_x emissions. The emission regulations can vary by boiler size and can be specified as:

- A ceiling emission rate (lb of pollutant/10^6 Btu of fuel burned)
- A recommended percentage removal (e.g., 90 percent removal of uncontrolled SO_2 emissions)
- A recommended percentage removal and a "floor" emissions rate (e.g., 90 percent removal until 258 ng/J -- 0.6 lb/10^6 Btu -- is achieved)
- A minimum percentage removal to be applied if the recommended percentage removal results in controlled emission rates lower than the "floor"

Fuel Choice Approach

The ICE Model's fuel choice decisions are a function of technical as well as economic and regulatory factors. The ICE Model evaluates fuel switching in existing boilers and fuel type selection in new boilers. The ICE Model selects from a wide range of fuel quality options (multiple residual fuel oil and coal types) and alternative pollution control strategies, as described above.

The ICE Model focuses on boiler fuel choice decisions between coal, oil, and natural gas. The model determines fuel choices for boilers using projected industrial fuel prices and total fossil fuel demand. The ICE Model does not consider feedstock energy uses (i.e., metallurgical coal or raw materials derived from petroleum or natural gas in the chemical industry) or energy consumption in process heat applications.

The fuel choice decision criterion for new industrial boilers is based on an analysis of recent industrial boiler orders. It is a function of boiler size and previous coal experience as well as cost differences. Existing industrial boilers may switch fuels and/or add pollution control equipment in response to fuel price forecasts or changes in environmental regulations.

User Options

"User options" are defined to be frequent user modifications to a subset of the model input files. The ICE Model user options can be classified in two groups:

- Alternative New Source Performance Standards (NSPS)
- "Energy scenario" specifications

Alternative NSPS refers to alternative Federal air emissions standards for SO_2, PM, and NO_x emissions from the combustion of coal, distillate fuel oil, residual fuel oil, and natural gas in new industrial boilers. Energy scenario specifications are exogenous regional projections of:

- Industrial fossil fuel prices
- Total industrial boiler fossil fuel demand

Model users may specify emissions ceilings by boiler size category, annual capacity utilization rate (less than or greater than 30 percent), pollutant, and fuel type (SO_2 for residual fuel oil; SO_2 and PM for coal) in terms of pounds of emissions per million Btu of fuel consumption.

Mandatory scrubbing can also be required for new industrial residual fuel oil and coal boilers by size class. The SO_2 percentage removal requirement can be fixed (constant for all fuel types regardless of sulfur content) or variable (function of the sulfur content of the fuel, such as the current electric utility coal-fired boiler NSPS).

The emissions standards, when expressed as an emissions ceiling ($lb/10^6$ Btu), limit compliance alternatives. For example, a mechanical collector is assumed not to be able to comply with a very low (e.g., 0.05 $lb/10^6$ Btu) coal PM emission regulation. A very low (e.g., 0.2 $lb/10^6$ Btu) coal SO_2 emissions ceiling will restrict coal compliance options to scrubbing low sulfur coals.

The ICE Model has the capability of applying alternative emission control options beginning in 1985. However, alternative nationwide SO_2 emissions standards for existing industrial residual fuel oil and coal boilers can also be specified. Existing boilers may be subject to revised SO_2 emission regulations related to acid deposition control strategies.

Projected delivered industrial fuel prices are required for the following fuel types:

- Natural gas
- Distillate fuel oil
- Residual fuel oil (four types at 3.0, 1.6, 0.8, and 0.3 percent sulfur)
- Coal (up to 11 types, currently ranging from 0.95 lb $SO_2/10^6$ Btu to 5.5 lb $SO_2/10^6$ Btu).

Fuel prices are required for 5-year increments (1980-2045) and by Federal region in constant 1980 $¢/10^6$ Btu.

Total projected industrial boiler fossil fuel demand is an exogenous parameter. "Total industrial boiler fossil fuel demand" is defined to include only the sum of:

- Natural gas
- Distillate and residual fuel oils
- Coal

Fuel demand projections are required by State, industry group, and year (1985, 1990, 1995, 2000, 2010, 2020, and 2030).

There are seven industry groups in the ICE Model:

- Food
- Textiles
- Paper
- Chemicals
- Petroleum refining
- Primary metals
- Other industrial

Total projected industrial boiler fossil fuel demand is an exogenous parameter because the ICE Model is one of a group of NAPAP sectoral emissions models. Input specifications for all of the NAPAP sectoral emissions models are coordinated by EPA and DOE in order that ICE Model results are compatible with other NAPAP models and with the latest biennial DOE National Energy Policy Plan forecasts.

Fuel Choice Decisions

The fuel choice decision framework in simulation models is usually based on the premise that industry will try to minimize the total costs of generating steam or heat over the useful life of the facility. Specifically, decision-makers will tend to select that fuel with the lowest expected life cycle costs.

This approach does not take into account non-economic factors which also may affect the fuel choice decision. Examples of other factors include:

- Site-specific conditions (i.e., capital availability, space for a coal pile)
- Previous experience with burning coal
- Perception of fuel supply reliability and price stability

The ICE Model Technical Advisory Committee decided that, for new boiler fuel choice decisions, the least-cost approach should be modified based on an empirical analysis of recent industrial boiler sales data. The fuel choice decision criteria should not be solely a function of expected cost differences.

Data on new industrial boiler sales were evaluated. This data base included over 400 orders for new industrial coal, oil, and gas boilers since 1977. The probability of selecting coal was estimated, using this data base, as a function of boiler size, previous coal experience, and expected cost differences.

For a given set of projected fuel prices and government policies (energy, environmental, and tax), the ICE Model calculates total after-tax net present values (NPV) by fuel type for each new industrial boiler record and selects the primary fuel type as follows:

1) Estimate the boiler capital and annual non-fuel O&M costs for each fuel type (oil, gas, and coal).

2) Estimate the capital and annual non-fuel O&M costs for applicable pollution control equipment options for each fuel type.

3) For each combination of fuel type and alternative pollution control equipment configuration, the after-tax NPV of total boiler and pollution control equipment capital and annual non-fuel O&M costs is calculated.

4) The after-tax NPV of projected fuel costs is derived and added to the total after-tax NPV of capital and annual non-fuel O&M costs for each fuel type/pollution control equipment configuration.

5) The total after-tax NPV is compared for each fuel type/pollution control equipment configuration, and the oil/gas alternative and the coal alternative with the lowest after-tax total costs are selected.

6) The cost difference (total oil/gas less total coal costs) is calculated.

7) An assumption is made whether or not this new industrial boiler will be located at a plant with previous coal burning experience, based on the historical percentage of plants in each region that currently burn coal in their boilers.

8) The probability of selecting coal is estimated based on the boiler size class, expected total after-tax NPV cost difference, and previous coal experience assumption.

9) A random variable is generated and compared with the estimated probability of selecting coal. If the random variable is less than the probability estimate, the fuel type selected is coal. If the random variable is larger than the probability estimate, the fuel type selected is fuel oil or natural gas (the alternative with the lowest total expected after-tax cost).

Existing boiler fuel choice is based solely on minimizing life-cycle boiler costs. The decision logic in steps 1 through 5 listed above is applied to existing industrial boilers.

Life cycle costs for new industrial boilers are compared in the ICE Model on an after-tax basis because Federal tax laws are different for oil/gas boilers than they are for coal units. The Energy Tax Act of 1978 (Title III) provided tax incentives for the use of coal and alternative fuels. New coal-fired boiler investments qualify for the regular 10 percent investment tax credit (ITC) and accelerated

depreciation methods. However, investments in new oil-and gas-fired boilers do not qualify for the regular ITC, and straight line depreciation is required for these units.

Simple relationships were derived relating the probability of installing coal-fired capability to boiler size, costs, and previous experience with coal. Work is still underway to refine these initial relationships. For new industrial boilers located in plants without previous coal experience, the probability of selecting coal is a function of the expected difference in total life-cycle costs (see Figure 3):

- If the boiler size is larger than 73 MW (250 x 10^6 Btu/hr), the probability of selecting coal ranges from 55 to 90 percent
- If the boiler size is 29-73 MW (100-250 x 10^6 Btu/hr), the probability of selecting coal ranges from 25 to 55 percent
- If the boiler size is less than 29 MW (100 x 10^6 Btu/hr), the probability of selecting coal ranges from 9 to 35 percent.

For new industrial boilers to be sited in plants with previous coal experience, the probability of selecting coal varied only with boiler size, not as a function of costs:

- Larger than 73 MW (250 x 10^6 Btu/hr), the probability of selecting coal is 95 percent
- Between 29 and 73 MW (100 and 250 x 10^6 Btu/hr), the probability of selecting coal is 89 percent
- Less than 29 MW (100 x 10^6 Btu/hr), the probability of selecting coal is 27 percent

There are two steps in the model related to accounting for coal experience. First, each new boiler created in the model has to be "located" in a plant with or without coal experience. Second, the model has to be able to track the population of boilers over time according to the presence/absence of coal experience. This latter point is necessary since the share of boilers in plants with coal experience will vary over time as a function of new boiler decisions and retirement assumptions.

Levels of coal experience are estimated by Federal region and boiler size. Obviously, we will not know exactly where new boilers will be located in the future. Hence, in the initial forecast year, the experience factor (e.g., probability of being located in a plant which has coal experience) is based on recent, but historical, data.

About 70 percent of industrial coal use is concentrated in only three regions of the country: Middle Atlantic (Region 3), South Atlantic (Region 4), and the Midwest (Region 5). Using EPA's NEDS inventory of boiler data organized by plant, roughly 17 percent of the plants in the above three regions had coal experience. For the other regions, only 2 percent of the plants had coal experience. Relying on the same boiler survey data used to derive the decision algorithms, the prevalence of experience was further distinguished

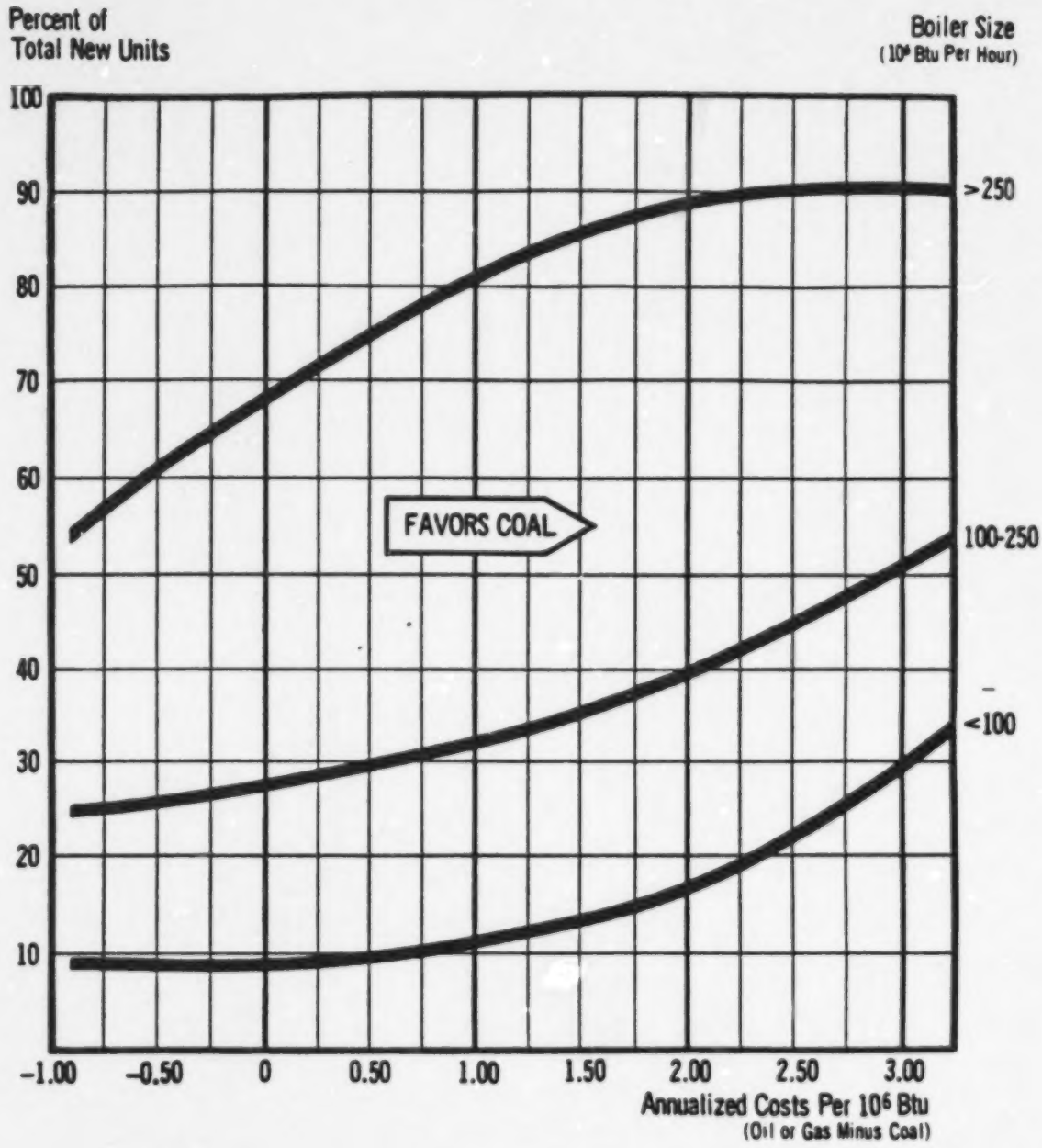

Figure 3 ICE model coal market share for new industrial boilers.
(In plants without previous coal-burning experience.)

by boiler size for the two larger size classes. The proportion of industrial plants with previous coal experience is allowed to change over time as new coal boilers are ordered for plants without previous experience.

As described above, the previous coal experience parameter, expected costs by fuel type, and the probability of selecting coal are estimated for each new industrial boiler in the ICE Model. A two-digit random variable is also generated (a different random variable than the value used to assign the previous coal experience parameter) for each new industrial boiler. Coal is chosen as the fuel type if the value of the random variable is less than or equal to the estimated probability of selecting coal (a percentage) for that individual record. If the random variable is greater than this estimated probability, residual or distillate fuel oil or natural gas (the alternative with the lower total after-tax NPV) is selected.

Conclusions

The ICE Model provides a valuable tool to government, industry, and other interested parties to assess the cost and emission reduction potential of alternative regulatory strategies. The results from this model can be merged with projections of the cost-effectiveness of controlling other key emitting sectors to determine the optimum control strategy. Current plans of NAPAP call for use of the ICE Model in future assessment activities of this nature.

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